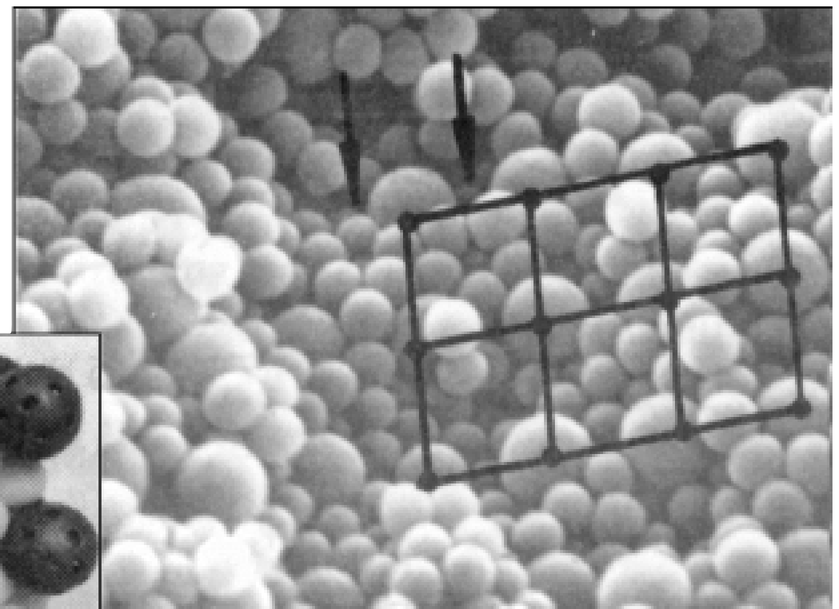
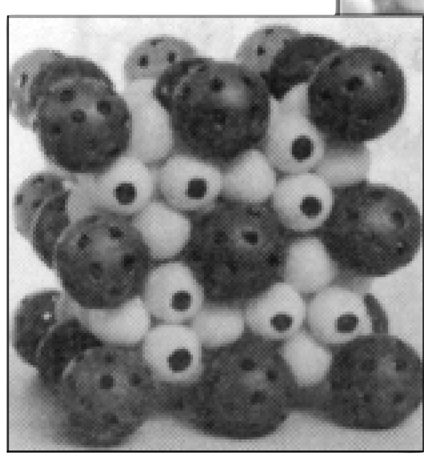
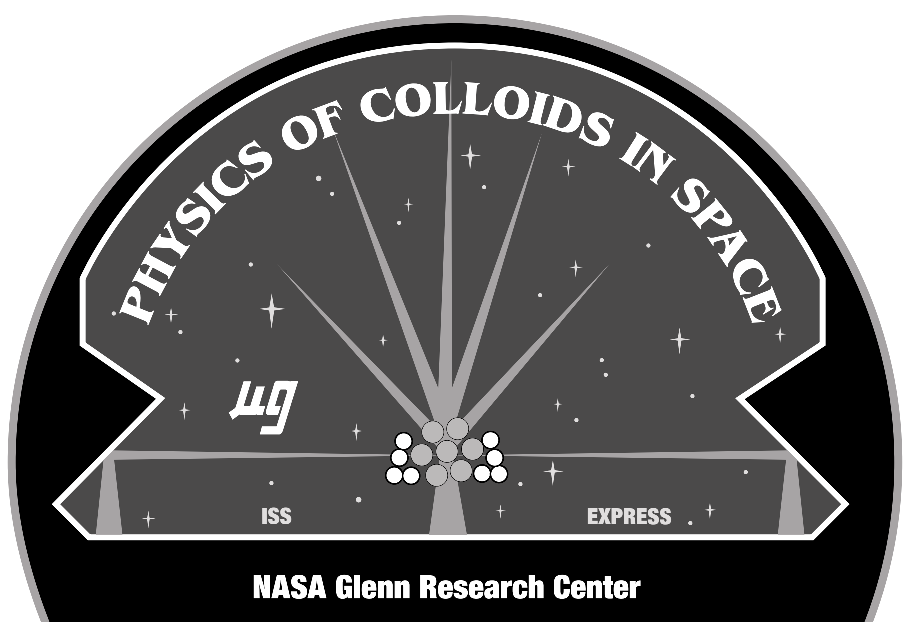
Physics of Colloids in Space (PCS)







National Aeronautics and
Space Administration
Glenn Research Center

Space Directorate
Microgravity Science Division

INTRODUCTION

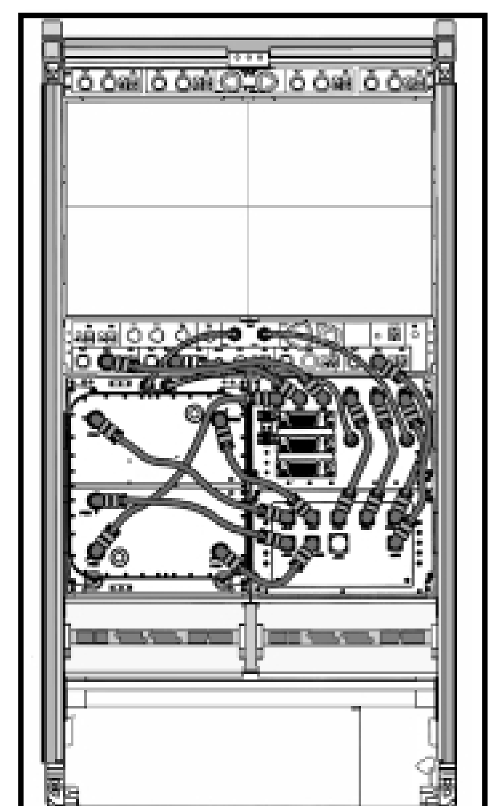
The Physics of Colloids in Space (PCS) investigation, to be conducted in an EXPRESS (**EX**pedite the **PR**ocess of **E**xperiments to **S**pace **S**tation) Rack, is planned to be performed in the International Space Station (ISS) U.S. Lab during the station assembly period, from flight 6A in the year 2000 to flight UF-2. This experiment will gather data on the basic physical properties of colloids by studying three different colloid systems with the objective of understanding how they grow and behave, and the long-term goal of learning how to steer their growth in order to create new materials.

The results from this PCS phase of the science investigation will be used for a second phase, which will attempt to fabricate novel materials from new combinations or structures with unique physical and optical properties to be used as optical switches and filters. Ultimately, "colloidal engineering" will be performed from insights and knowledge obtained in this and other experiments.

This experiment is part of a two-stage investigation conceived by David Weitz of Harvard University along with Peter Pusey of the University of Edinburgh. The investigation is managed by John Koudelka of the Microgravity Science Division at NASA Glenn Research Center and is supported by the NASA MSFC Microgravity Research Program Office and NASA Headquarters Office of Life and Microgravity Science and Applications.

SCIENCE OVERVIEW

A colloidal suspension consists of fine (about 100 to 100,000 times smaller than the thickness of a human hair) particles suspended in a fluid. They are found almost everywhere in nature and are used in industrial processes. Such varied systems as aerosols, foams, paints, pigments, cosmetics, milk, salad dressings, and biological cells are examples of colloidal dispersions or suspensions. Colloidal particles (spheres) can also serve as model systems for the study of the properties of fluids and solids because they can be considered as playing the role of atoms. Even uniformly sized spheres that cannot penetrate each other and do not otherwise interact (hard spheres) undergo a change from a disordered liquid state to an ordered solid state under the proper conditions, just as water molecules become ordered to form ice.

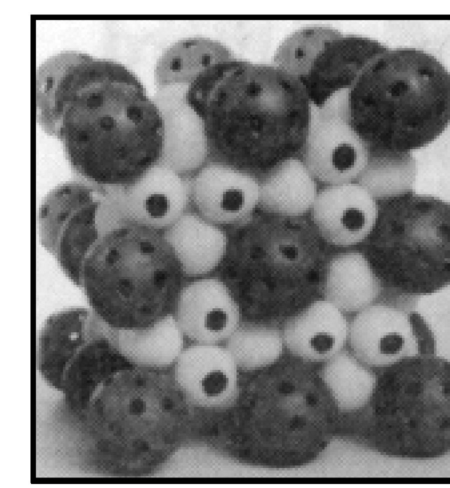


PCS in EXPRESS Rack.

In appropriate conditions, colloidal particles can self-assemble into structures showing crystalline order. Brownian motion (collisions between liquid suspension molecules and the particles) causes the formation of ordered arrays or crystals. On Earth, the movement of the spheres is mostly directed by sedimentation and buoyancy flows (e.g., hot air rises), which prevent self-assembly. The microgravity environment of orbital space flight eliminates gravity-induced sedimentation and flow improving the particle self assembly.

The types of structures formed from self-assembly are dependent on the quantity (volume fraction) of the spheres in solution, their size, and the interactions between them. The PCS investigation looks at three different sample structure types with different volume fractions or interactive bond strength—binary colloidal alloys, colloid-polymer, and fractal aggregates.

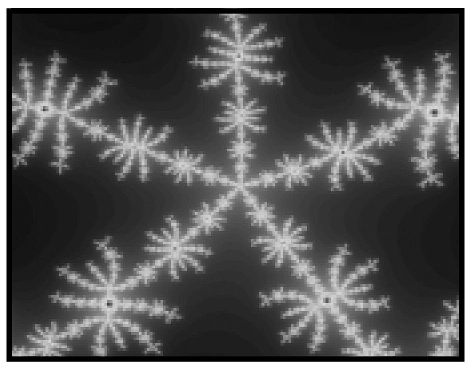
Binary colloidal alloys consist of two plastic (polymethl methacrylate (PMMA)) spheres of different sizes in a decalin-tetralin solution. PMMA spheres are used because of their extensive use in current ground-based research and their compatibility with the diagnostics used to determine growth and structure characteristics. For the microgravity studies, the particle size ratio and particle volume fraction is varied in order to develop different crystalline structures. It has been found that particles at a size ratio of 0.58 can form both a simple hexagonal arrangement of large particles with the smaller particles in between (AB_2), or a complex structure of icosohedral (20-faced polygon) clusters of small particles centered in cubic lattice of large particles (AB_{13}). Once the conditions (particle ratio, volume fraction) to create specific structures are understood, particles of different materials can be used in place of the PMMA to create new materials with unique physical and optical properties. These new materials could possibly be used as optical switches or filters, or as photonic band gap materials.



Binary colloidal alloy.

Colloid-polymer samples use plastic spheres of the same size and introduce a non-adsorbing polymer to the colloid. The addition of a polymer changes the attractions between the spheres in solution; more polymer yields higher strengths of attraction. The microgravity study will investigate the liquid, transition (critical point), and solid (crystalline) nature of the solutions.

Fractal aggregate samples are water solutions of nanometer-size silica or polystyrene particles. Samples in this class are very weak gels that have fractal structure. Aggregation of the particles is irreversible and initiated by addition of a salt solution (sodium chloride or magnesium chloride with water) to the particle solution. Fractal structures have the characteristic of having the same pattern repeat itself at smaller scale again and again. A tree is considered a fractal because its branches look like smaller trees; and the smaller branches look like even smaller trees, etc. A snowflake and a fern are also good examples of fractal structures.

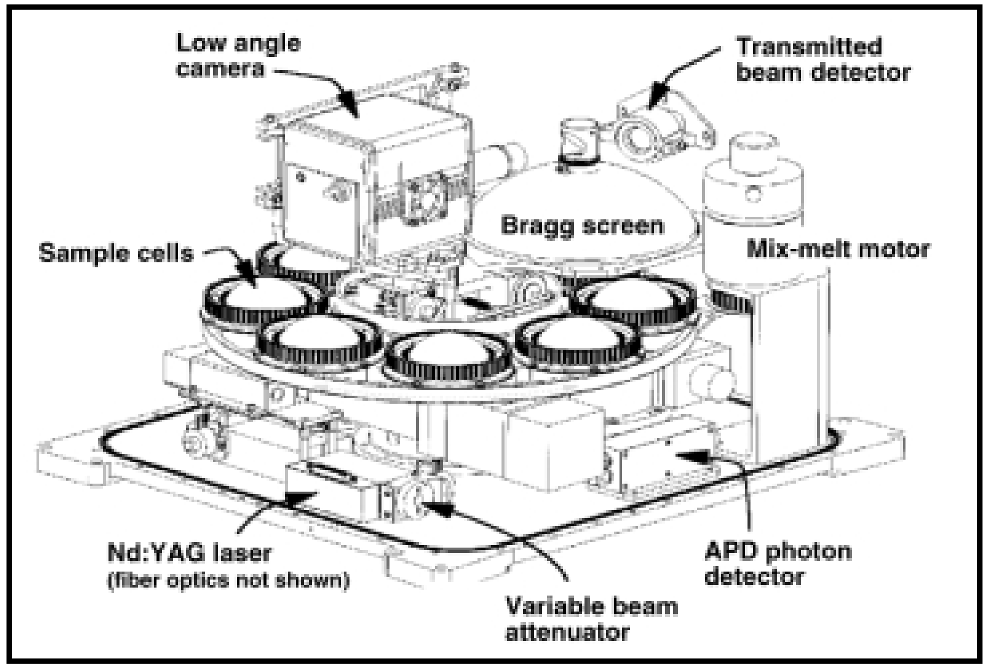


Snowflake: an example of a fractal structure.

HARDWARE OVERVIEW

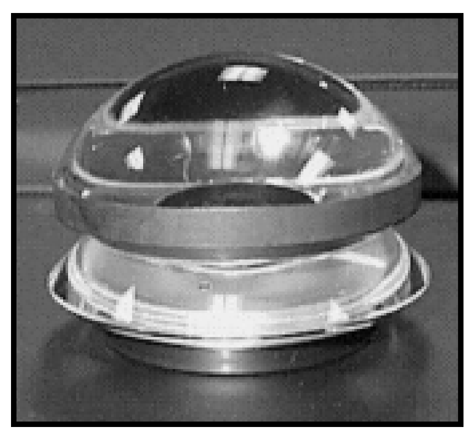
The first generation of hardware to investigate colloidal suspensions in microgravity was Glovebox experiment hardware, flown on the Space Shuttle and the Russian Space Station Mir. The Glovebox experiments were BCAT (Binary Colloid Assembly Test) and CGEL (Colloidal Gelation). PCS is thus the second generation of experiment hardware to address the first phase of Prof. Weitz's science investigations. The PCS hardware is based directly on the Physics of Hard Spheres Experiment (PHaSE) hardware, which was assembled and flown on the MSL–1 Spacelab Shuttle flight in 1997. PhaSE was flown in support of colloid physics research by Paul Chaikin of Princeton University.

The PCS experiment hardware is composed of an avionics unit and a test section unit, each approximately 47 by 50 by 56 cm. The test section and avionics section are accommodated side-by-side in an EXPRESS Rack and occupy the equivalent space of four middeck lockers. The PCS hardware relies on the EXPRESS Rack systems for power, cooling, and communication (for data and commanding from the ground). The PCS avionics section provides the power distribution, data acquisition and processing, and command and data communication for the experiment. It is a two-drawer assembly within an aluminum enclosure. The upper drawer holds the power control module, current sensors, circuit breakers, and three removable hard drives, two of which are used for data storage and the third used for operating system software. The lower drawer contains the data acquisition boards on a PCI–ISA bus. Both drawers have fans to circulate air for cooling and the upper drawer has a water loop to cool the power control module.



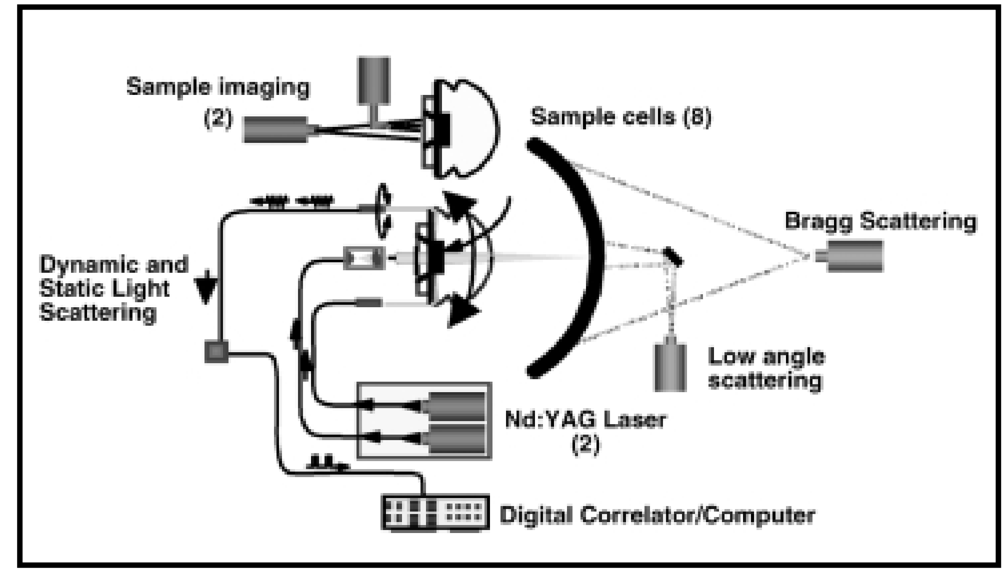
Test section internals.

The PCS test section is a sealed enclosure assembly that houses all diagnostic components and eight colloid samples in a rotating carousel. The carousel and rotary stage position any of the eight samples into the three diagnostic stations. Two of the stations are for visual imaging; one is a full sample view and the other is a magnified view. The third station is for laser light-scattering diagnostics. The sample particles and later formations scatter light at different degrees of intensity and positions based on the type and size of structures formed. To support the light-scattering and the visual imaging, the samples are contained in a glass optical sample cell. The cell consists of a spherical lens top and a parabolic skirt (see below).



Optical sample cell.

The spherical lens and the parabolic skirt provide a path for the incident laser light to the sample solution/formation, and directs the scattered light to the recording diagnostic. The spherical lens supports the low angle imaging and Bragg scattering imaging via two digital video cameras. The parabolic skirt provides for the dynamic and static light-scattering data; scattered light is detected by two Avalanche Photo Diodes (APD's).



PCS diagnostics.

OPERATIONAL SEQUENCE

The test section is installed in the shuttle middeck for transport to the ISS, which permits late sample processing via delivery of the unit to Kennedy Space Center days before the launch. The avionics section as well as stowage items are installed in the EXPRESS Rack in the multi-purpose logistics module (MPLM), a shuttle cargo bay carrier for transport to the ISS. Once docked to the Station, the units will be transferred to the U.S. Lab where the test section is installed next to the avionics section in the EXPRESS Rack.

Experiment operations consist of mixing the colloid samples to eliminate any sedimentation and to produce a uniform distribution of particles in the solution. Once mixed, the self-assembly of particles will start and the diagnostic measurements are initiated. The measurements are taken for each sample periodically (a few times each week) over several months on-orbit. The diagnostic data will provide growth information, the shape of the structures formed, and other physical properties of the structures.

The experiment operations are conducted by ground commanding. Ground commands will be issued from the NASA Glenn Research Center's Telescience Support Center and at an established remote site at Harvard University. The two locations permit daily operation of the PCS experiment by the science team and/or the PCS project team. The purpose of this is to bring the experiment conducted in space to the scientists at their workplace. All the data is stored on the on-orbit removable hard drives with portions of the data transmitted in real time to the ground stations. Complete diagnostic data files will be downlinked at the conclusion of a day's operations when ISS resources are available. This data will be analyzed by the PI team to determine the sample growth status, and used to evaluate and plan the future operational runs.

Upon completion of the experiment, the test section, avionics sections, and PCS stowage items are transferred to the space shuttle for the return trip to Earth. The test section is stowed in the shuttle's middeck, and the avionics section and other stowage items in the MPLM.

POSTFLIGHT DATA ANALYSIS

During the mission operations, the downlinked data will be analyzed to determine the success of each individual experiment run. This information is used to plan the remaining experiment runs. The hard drives returned from space contain the full experiment data sets and will be further analyzed. The principal investigator's team will analyze the light-scattering data and digital images to determine the growth rates, structures formed, and the properties of the crystalline or fractal structures. The PI team will also conduct further experimentation with the flight hardware and samples to obtain 1-g growth data to compare to the flight microgravity results.

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